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# SHARED VIRTUAL ENVIRONMENTS FOR COLLECTIVE TRAINING

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## ABSTRACT

Historically NASA has trained teams of astronauts by bringing them to the Johnson Space Center in Houston to undergo generic training, followed by mission-specific training. This latter training begins after a crew has been selected for a mission (perhaps two years before the launch of that mission).

While some Space Shuttle flights have included an astronaut from a foreign country, the International Space Station will be consistently crewed by teams comprised of astronauts from two or more of the partner nations. The cost of training these international teams continues to grow in both monetary and personal terms. Thus, NASA has been seeking alternative training approaches for the International Space Station program.

Since 1994 we have been developing, testing, and refining shared virtual environments for astronaut team training, including the use of virtual environments for use while in or in transit to the task location. In parallel with this effort, we have also been preparing applications for training teams of military personnel engaged in peacekeeping missions. This paper will describe the applications developed to date, some of the technological challenges that have been overcome in their development, and the research performed to guide the development and to measure the efficacy of these shared environments as training tools.

## INTRODUCTION

Many Space Shuttle flights include an astronaut from a foreign country. These astronauts usually carry out most of their training at the Johnson Space Center in Houston or in special facilities at other NASA centers. These astronauts often relocate their entire family to Houston. Thus, the support of international crews for the Space Shuttle has been at great cost to the nation from which the astronaut comes and has had a high personal cost for both the astronaut and his or her family. The International Space Station (ISS) program is a partnership between NASA, the European Space Agency, the Japanese equivalent (NASDA), the Canadian Space Agency, and the Russian Space Agency. The four-person crews that will staff the ISS will be derived from the partner nations and will also include guest astronauts from other countries. For years those responsible for training astronauts for the ISS have grappled with the issue of training these international crews. In order to reduce the costs of such training and to address the "political" issues of where training should occur, the NASA training community has sought means of training teams of astronauts, to some extent, while each astronaut remains in his or her home country.

Since 1994, we have been exploring the application of shared virtual environments for the training of international teams of astronauts. This task has encompassed a number of issues. Among these are necessary communications bandwidth, communications latencies, data transfer protocols, interaction metaphors, human figure representations, necessary fidelity (visual, audio, haptic), navigation methods, training transfer, and the psychology of team building.

In addition, the long duration and complexity of ISS missions precludes training personnel for all possible operations prior to the mission's commencement. Moreover, certain skills and knowledge acquired prior to a mission may degrade during the month's-long duration of typical ISS stays. Thus, VEs are being investigated to serve as delivery mechanisms for "just-in-time" training. In this case these systems could provide training just prior to the performance of a critical task for which no training was delivered prior to the flight or for which skills or knowledge may have degraded. It should also be possible to transmit new or updated databases to such space-based VEs to address specific unforeseen problems.

## HUBBLE SPACE TELESCOPE MISSION

In December, 1993 the Space Shuttle captured the Hubble Space Telescope (HST), and astronauts carried out a complex set of procedures to correct its mirror's optical problems, replace and upgrade certain instruments, and carry

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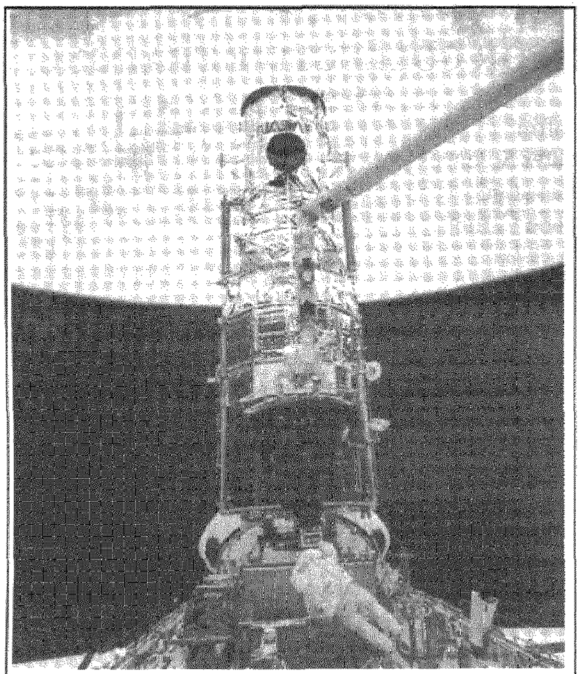


**Figure 1. A team of astronauts prepares to maintain the Hubble Space Telescope during the December, 1993 mission**

out planned maintenance (see Figure 1). This mission, by most measures, was the most challenging mission ever performed in the history of the United States' manned space program. Preparation for the mission was the most careful and detailed and brought unique resources to bear for the training of both astronauts and the ground-based flight team. In order to achieve the maximum state of readiness, virtual environments were used, for the first time, in the training of the flight team [Loftin, 1995]. This use of virtual environments for training joins a small set of applications that demonstrate the efficacy of this technology for training. Shortly after the conclusion of this mission, interest in using shared virtual environments to train international teams of astronauts emerged as a high priority within NASA's training community. NASA, the University of Houston, and the Fraunhofer Institute for Computer Graphics joined together to pursue an initial effort to determine the feasibility of a shared virtual environment for team training. The context for the feasibility study took the form of a simple extravehicular (EVA) simulation that engaged two astronauts, one located at JSC and the other in Darmstadt, Germany to reenact a portion of the 1993 HST mission. In this simulation, the two astronauts changed out the Solar Array Drive Electronics (SADE) in the HST.

Months of preparation culminated in a demonstration on September 20, 1995, as Astronaut Bernard Harris (physically located in Houston at the Johnson Space Center) entered a virtual environment with Astronaut Ulf Merbold (physically located at the Fraunhofer Institute for Computer Graphics in Darmstadt, Germany). Their shared environment consisted of models of the Space Shuttle payload bay and the Hubble Space Telescope. The two astronauts spent over thirty minutes performing the major activities associated with the changeout of SADE. Their work included the real-time hand-off of the replacement SADE in exchange for the original SADE. At the conclusion of the task the two astronauts shook hands and waved good-bye [Loftin, 1997]. Interviews with the astronauts after this experiment revealed their support of and interest in this mode of training. They confirmed its utility for mission planning and the familiarization phase of training and acknowledged its value in reducing travel and personal segregation from their families and home environments. The results of this singular experiment have led to sustained funding from NASA to continue developing the technologies needed for this type of training and to design and conduct experiments to identify human-human and human-machine issues that require solution if this approach to training is to become part of the baseline training for the International Space Station.

## INTERNATIONAL SPACE STATION

Based on the success of the Houston-Germany experiment described in the previous section, we have been developing a testbed around the International Space Station. The training focus of this testbed is the conduct of scientific experiments and the execution of repair and maintenance operations within the ISS. Models of the interiors of selected ISS modules have been created (see Figure 2) and populated with both highly detailed, interactive models (polygonal) of the elements for which training has been developed along with detailed but non-interactive models (texture mapped) of the remaining interior elements. The racks of equipment for which training is delivered in this virtual environment comprise the Biotechnology Facility (BTF). Prototypes of these racks are currently on-board the Russian Mir Space Station, affording opportunities to investigate training transfer for currently-performed tasks (see Figure 3).

A major distinction between this experimental testbed and the environment used in the Houston-Germany experiment described earlier is the transfer of the training context from extravehicular activities (EVA) to intravehicular activities (IVA). Whereas in the EVA environment astronauts were represented as "suited" individuals, employing rather simple graphics to represent their bodies, in the IVA environment, high fidelity human models were developed to serve as avatars for the actual participants in virtual environment training. This approach sets a much higher standard for the fidelity with which the humans are represented and challenges the developers to find a reasonable compromise between fidelity and graphics display performance (see Figure 4). Training participants are instrumented with sensors

Figure 2. Cross-sectional view of ISS science module

that enable real-time tracking of critical portions of their bodies (typically the head, torso, and wrists). Using fast inverse kinematics [Tolani, 1996], we have implemented avatar motion for the arms that reasonably represents the actual motion of the human arm during the operations carried out by the tracked real arm. Work is underway to further refine these inverse kinematics and achieve even faster performance and more natural positioning of the entire arm [Yang, 1997]. This work seeks to combine the best features of the analytic approach described by Tolani and Badler [Tolani, 1996] with experimental results from neurophysiological studies [Lacquaniti, 1982; Soechting, 1989a; Soechting, 1989b]. Leg motion is not implemented in the current environment since it does not play a major role (at least in the sense of walking on the Earth's surface) for location in microgravity. Eventually, we will have to tackle this problem since leg position is important in some tasks where the human must exert substantial forces or torques on objects.

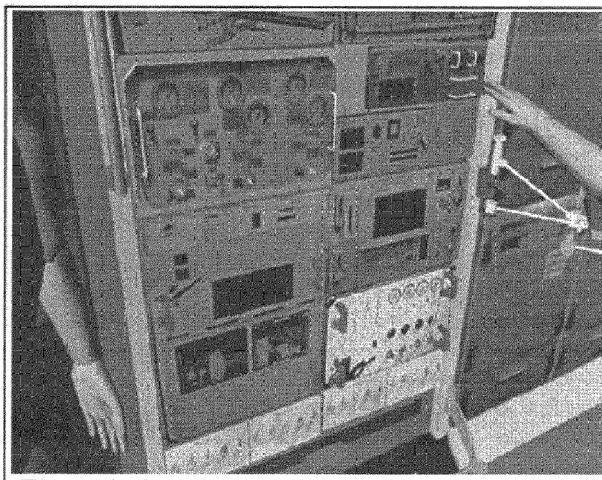


Figure 3. Model of the Biotechnology Facility in the ISS and on the Russian Mir Space Station

The current testbed has been implemented at three sites to support experiments in training two astronauts while other personnel (trainers or managers) are able to view the actions of the trainees via a "stealth" mode. That is, the stealth view is a stereo camera view that can be positioned anywhere in the virtual environment but has no manifestation in that environment that can be perceived by the trainees. Final experimental procedures are now being developed in preparation for controlled experiments using this testbed. The goal of these experiments will be a training transfer study to the "real" hardware (either in the Russian Mir Space Station or on the ground once the equipment is returned to Houston).

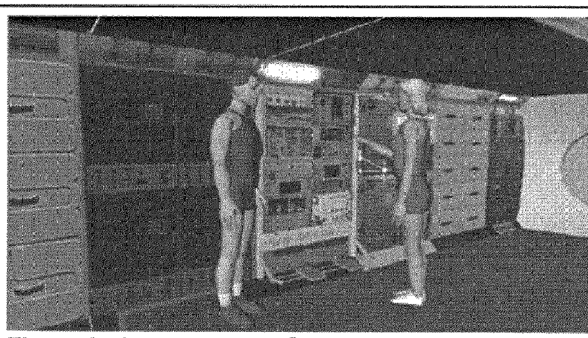


Figure 4. Avatars are used to represent astronauts in the ISS virtual environment

It should be noted that a major current thrust is directed at enabling the use of virtual environments in space to support "just-in-time" training. Such training, in low Earth orbit, might include environments shared by astronauts in the ISS and ground-based engineers and other professionals. Such an approach has been suggested for both emergency repair of complex systems and the conduct of medical procedures in response to serious injuries or illnesses that might be encountered during long-duration space missions.

## PEACEKEEPING OPERATIONS

With support from the Office of Naval Research, a group (comprised of the University of Houston, the University of Pennsylvania, George Mason University, LinCom Corporation, and Lockheed-Martin) has been conducting basic research and applying its results to develop a prototype application to address training of military personnel in Peacekeeping Operations. Work has been carried out in two areas of basic research: team training in virtual environments and the utility of virtual environments to support nonverbal human-human communication.

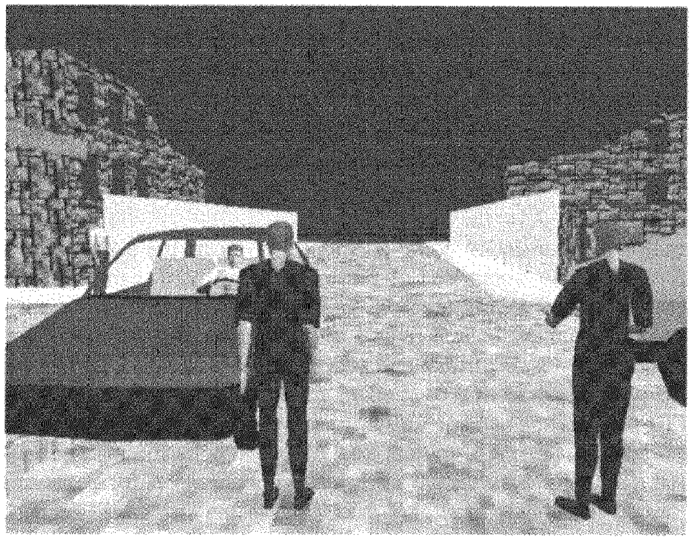
The context for the virtual environment application that is under development is a checkpoint in a Bosnian setting (see Figure 5). This scenario offers a versatile testbed for investigating the use of shared virtual environments for training small units (fire teams and squads) for carrying out peacekeeping operations in a potentially hostile location where the focus is on employing the Rules of Engagement in the face of potentially unfriendly civilians and an enemy operating in a covert manner.

**Figure 5 – A U.S. soldier manning a Bosnian**

This application is being used to investigate the degree of training transfer to similar, real-world settings (see Figure 6). In particular, we seek to challenge the trainees with distracters and to enable them to experience the consequences of failure to employ correct procedures and follow the Rules of Engagement. A typical training scenario might employ a distracter (an individual running across the soldier's field of view) aimed at drawing the attention of the covering soldier away from his teammate while that partner is engaged in checking the identification of the driver of a car stopped at a checkpoint. If the trainee's attention is drawn from "covering" his teammate, the consequence could be the driver taking a weapon from concealment and shooting the soldier who is attempting to check his identification. Thus, the results of distraction from one's assigned mission, can be forcefully brought home to the trainee.

In tandem with this application development we have been conducting a series of experiments in both team training transfer [Bliss, 1997] and nonverbal communication. The first experiments have focused on team navigation skills. A larger study is now underway, in collaboration with the Army Research Institute (Orlando Field Unit), to determine how well navigation skills acquired as a team in a virtual environment transfer to the setting represented by the virtual environment.

**Figure 6. Scene from Peacekeeping Operations Environment**



The second set of studies has not yet been subjected to peer review, but results of two separate experiments have been analyzed. These results demonstrate that subjects in typical virtual environments can reliably recognize stereotyped and some subtle human facial expressions. The reliability of recognition is comparable to that achieved by the subjects viewing photographs depicting the same expressions. Experiments are now being designed to investigate the degree to which the application that we have developed can provide training that is transferable to real-world analogues.

## *IN SITU* TRAINING

NASA astronauts have consistently noted the need for training during spaceflight, even relatively short-duration Space Shuttle missions. Apparently they believe that some skills, such as landing the Space Shuttle, deteriorate during a two-to-three-week-long mission. In response, NASA has developed a PC-based system, delivered via a laptop computer, for landing refresher training. As mission lengths grow (e.g., International Space Station stays and future Lunar/Mars missions) from weeks to months and years, NASA must systematically address *in situ* training for crews. Clearly, much of this training can be provided via standard computer-based techniques. However, there are a significant number of tasks that demand interactive, three-dimensional representations in order to achieve the needed degree of realism (both visually and through body orientation and manipulation by hand). For example, astronauts currently plan their body placements for many tasks using virtual environments. Thus, research and development is underway to address the delivery of some training in space using virtual environment technology. The first virtual environment system will be flown aboard the Space Shuttle in mid-1998 as a part of Neurolab (STS-90). Although this system is intended for use in a human perception experiment, its development and flight clears the way for future space-based experiments that utilize virtual environments for training. It is anticipated that such an experiment will be conducted during a mission in late 1999 or early 2000. The success of this type of experiment will likely lead to the incorporation of a virtual environment within the International Space Station.

In addition to applications during long-duration Space Shuttle missions and aboard the International Space Station (both of which occupy low earth orbits), it is probable that virtual environments will be required for any human mission to the lunar surface or to Mars. In the latter case, transit times will exceed one year with total mission time occupying three or more years. Moreover, communication lags can reach thirty minutes and there can be significant periods (months in length) with no communication at all due to particular Earth-Sun-Mars alignments.

## IMPLICATIONS FOR NATO

Other papers in this workshop have addressed the use of virtual environments for a variety of military training applications. The specific projects described in this paper, while not designed for typical warfighting training, do provide a basis for developing and/or improving virtual environment training for a variety of modern military missions. In particular, the application of virtual environments for peacekeeping mission training should be of interest to NATO, given its current role in Bosnia.

The use of virtual environments (both individual and shared) for small unit mission planning and training offers a number of benefits. For example, unit commanders can plan and review tactics with appropriate superiors and subordinates. Whole units (or parts thereof) can rehearse entire missions or critical mission elements to resolve such issues as timing and personnel placement. Perhaps most importantly many options for attaining a specific mission objective can be quickly explored during the mission planning phase. Such an approach will likely result in a significant increase in the probability of mission success and a concomitant reduction in the likelihood of casualties (both military and civilian).

Since NATO is a multi-national organization joint operations, even at the small unit level, are likely. Shared environments offer the ability for units, comprised of personnel from more than one service and/or more than one nation, to rehearse a mission while they are still in their "home" locations or even in transit to the site of operations. Such an application of virtual environments could reduce response time. In addition, the time spent in these shared environments could lead to increased levels of trust and cohesion among individuals who have never met prior to the conduct of a mission. Finally, a characteristic of modern military operations is the fluidity of team composition. Teams may be constituted for a specific objective within the context of a larger mission. Such teams may only exist for hours or days, at most. The achievement of mutual trust and team cohesion may be impossible if traditional team training approaches are used. Again, shared virtual environments between participants in their "home" locations or while in transit to the site of operations may have give these fluid teams the "edge" needed to succeed in the modern battlespace.

## ACKNOWLEDGMENTS

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